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14. ABSTRACT
We have extended our 3D spectral/spatial Gabor representation to consider the effects of three-dimensional scene structure in hyperspectral images. We have shown that traditional spectral/spatial models lead to ambiguities when classifying image regions due, in part, to changes that occur as the environmental conditions change. Our new models characterize the variation

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Report Title

Advanced Methods for Representing and Processing Hyperspectral Image Data

ABSTRACT

We have extended our 3D spectral/spatial Gabor representation to consider the effects of three-dimensional scene structure in hyperspectral images. We have shown that traditional spectral/spatial models lead to ambiguities when classifying image regions due, in part, to changes that occur as the environmental conditions change. Our new models characterize the variation of vectors that are derived using spectral/spatial features as the scene conditions change. We have shown that these models improve on the properties of standard techniques. The utility of this approach has been demonstrated using thousands of hyperspectral image regions that have been generated over a broad range of conditions. We have also modeled the effect on hyperspectral image sequences of ballistic impacts. We have shown that the multiband Gabor representation allows extraction of image properties that can be used to estimate properties of the impact. We have also applied the models to human skin in near-infrared images and demonstated the potential for tissue classification.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

G. Healey, "Invariant Methods for Hyperspectral Image Processing," Plenary lecture, SPIE Annual Meeting, San Diego, August 2012.

Number of Presentations: 1.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Glenn Healey was recognized as a Fellow of SPIE. He was also selected as a speaker at the Boeing Frontier Lecture Series and delivered a plenary talk at the annual SPIE Photonics Conference in San Diego.

Graduate Students

NAME PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Names of Post Doctorates

NAME PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Names of Faculty Supported

NAME PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Names of Under Graduate students supported

NAME PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......	0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):......	0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:......	0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

We have implemented a method for generating a 3D Gabor filter bank for the representation of hyperspectral image data. We have used this approach to generate compact expressive models for hyperspectral image regions. We have also derived methods for selecting filters that emphasize the most significant spectral/spatial differences between classes. We have shown that the new approach can be used for accurate clutter classification in AVIRIS hyperspectral images using a small number of features. We have extended this approach for the modeling of environmental effects on images of 3D structures by using subspaces of multidimensional Gabor features. These models have been validated by generating several thousand images of 3-D scenes using DIRSIG. We have also performed detailed comparisons of the new models and methods with previous approaches. Our researchers have also developed new methods for the realistic synthesis of spectral/spatial data using an iterative approach. We are also modeling the thermal properties of tissue and changes that occur in response to ballistic impacts. These models have been used to synthesize hyperspectral image sequences that demonstrate the thermal response of tissue to ballistic impacts. Banks of multi-dimensional Gabor filters have also been used to extract properties of the images that allow estimation of properties of the impact. In addition, we are considering the use of skin models for invariant hyperspectral face recognition. We have shown that the models improve performance for the invariant recognition of faces in three dimensions.

Technology Transfer

Final Report

Title: Advanced Methods for Representing and Processing Hyperspectral Image Data

Proposal Number: 52762-CI

Award Number: W911NF-08-1-0183

Principal Investigator: Glenn Healey, EECS Department, UC Irvine

ARO Program Manager: Liyi Dai, Computing Sciences Division

Date: 5 March 2012

1 Objectives

Hyperspectral imaging (HSI) sensors provide the opportunity to address a wide range of applications. The large number of spectral bands obtained by these instruments makes it possible to use spectral information to perform image analysis tasks that are not feasible using other sensors. In this project we have developed innovative models for HSI data. The new models utilize multi-dimensional Gabor functions for the extraction of spectral/spatial information from images at different orientations and scales. These functions provide an efficient means of sampling a multi-dimensional frequency domain representation of HSI data. In order to reduce the dimensionality of the data we have developed general methods for the optimal selection of multi-dimensional Gabor functions that capture the most significant spectral/spatial information for a given application. We have also considered the use of multi-dimensional Gabor filters for modeling time sequences of hyperspectral images. This approach is being used for the modeling and analysis of kinetic energy effects on mammal tissues against ballistic impacts. HSI sensors have the unique capability of obtaining under-skin thermal characteristics of the ballistic impacts on mammal tissues. The focus is on the analysis and understanding of hyperspectral image data and the development of rigorous mathematical models to characterize ballistic impacts. The proposed approach can also be applied to the study of blunt trauma and impulse loading. The generality of our approach enables the new methods to advance the state-of-the-art for other application areas such as target detection and clutter classification. Specific objectives for this project are listed below.

Objective 1: Develop methods to utilize 3D and 4D Gabor filters to extract spectral/spatial/temporal information from hyperspectral images and image sequences.

Objective 2: Develop optimized methods for reducing the dimensionality of the Gabor representation.

Objective 3: Apply the new approach to applications including the analysis of ballistic impacts, target detection, face recognition, and clutter classification.

Objective 4: Transfer the new models and methods to DoD users.

2 Approach

The spectral/spatial DFT provides a general model for spectral/spatial image structure and can be inverted to recover the radiance domain data. However, the cost of this generality is the size of the representation. Thus, spectral/spatial models with fewer parameters are desirable. Markov random fields (MRFs) have been used for hyperspectral image modeling. These models provide a compact image representation by restricting the dependence of the data at a pixel to a defined set of neighboring pixels. However, we have demonstrated limitations of MRFs when applied to real data and other studies have shown empirical limitations of the models for various applications. Filter-based approaches have also been used to generate compact models for multispectral images. However, these approaches apply the filters to individual spectral bands and do not exploit the three-dimensional spectral/spatial structure of the data.

The spectral/spatial DFT represents an image region using a dense sampling in the frequency domain. An alternative approach is to represent the DFT by its projection onto a set of functions that capture specific orientation, scale, and spectral attributes of the image data. For this purpose, we use a new representation for spectral/spatial data using three-dimensional Gabor functions. Two-dimensional Gabor functions have been used to represent scale and orientation information in single-band image data for several applications. These functions achieve optimal joint localization in space and spatial frequency. Previous work has applied 2D Gabor functions to multiband images band-by-band or by considering opponent relationships between pairs of bands. Two-dimensional Gabor functions have also been used as the mother function to define a wavelet decomposition for 2D images. Other work has used wavelets to represent the spectral dimension in hyperspectral data. However, a general approach to representing spectral/spatial image data requires the use of 3D basis functions. We are also considering the use of 4D Gabor functions for the analysis of time sequences of hyperspectral images.

3D Gabor filters allow for a large number of spectral/spatial quantities to be used to represent an image region. The performance and efficiency of algorithms that use this representation can be improved if methods are available to reduce the dimensionality of the model. A standard goal in signal processing is to generate filtered images that can be used to reconstruct an approximation to an input image. This leads to a set of filters that minimizes the reconstruction error. However, for applications such as characterization and classification the primary goal is to find filters that emphasize the most significant information in a scene. Thus, we have derived new methods for selecting filters that are optimized for this goal.

3 Scientific Barriers

This research is the first attempt to use 3D and 4D Gabor filters to represent hyperspectral image data. Thus, there are a number of difficult scientific challenges that have been addressed. For example, there are important issues related to the relative scaling of the spectral, spatial, and temporal frequency dimensions that must be considered. In multiple dimensions there are a large number of correlations that can be taken into account. New methods have been developed for discovering and exploiting these correlations. We have also studied the state-of-the-art in modeling the thermal properties of tissue to understand the limitations of available models. In addition, we have been limited in our ability to obtain real hyperspectral data showing tissue response to ballistic impacts. There are also a large number of details that had to be addressed for various application areas.

4 Significance

In this project we have developed innovative models for spectral/spatial/temporal data that will lead to significant advancements in methods for automated image exploitation. The new models utilize three and four-dimensional Gabor functions for the extraction of spectral/spatial/temporal information from images at different orientations and scales. These functions achieve optimal joint localization in space and frequency and provide an efficient means of sampling a high-dimensional frequency domain representation of HSI data. We have used physical models to develop a mathematical structure for the image models that is invariant to complex changes in the environmental conditions in the presence of three-dimensional scene structure. In order to reduce the dimensionality of the data we have developed general methods for the optimal selection of three-dimensional Gabor functions that capture the most significant spectral/spatial information for a given dataset and application. We have demonstrated the significance of the new approach by detailed comparison with previous methods. The generality of the new methods has been shown by considering several applications which include the characterization of ballistic impacts, target detection, face recognition, and clutter characterization.

5 Accomplishments

We have implemented a method for generating a 3D Gabor filter bank for the representation of hyperspectral image data. We have used this approach to generate compact expressive models for hyperspectral image regions. We have also derived methods for selecting filters that emphasize the most significant spectral/spatial differences between classes. We have shown that the new approach can be used for accurate clutter classification in AVIRIS hyperspectral images using a small number of features. We have extended this approach for the modeling of environmental effects on images of 3D structures by using subspaces of multidimensional Gabor features. These models have been validated by generating several thousand images of 3-D scenes using DIRSIG. We have also performed detailed comparisons of the new models and methods with previous approaches. Our researchers have also developed new methods for the realistic synthesis of spectral/spatial data using an iterative approach. We have also modeled the thermal properties of tissue and changes that occur in response to ballistic impacts. These models have been used to synthesize hyperspectral image sequences that demonstrate the thermal response of tissue to ballistic impacts. Banks of multi-dimensional Gabor filters have also been used to extract properties of the images that allow estimation of properties of the impact. In addition, we have considered the use of skin models for invariant hyperspectral face recognition. We have shown that the models improve performance for the invariant recognition of faces in three dimensions.

6 Collaborations

We have presented results at conferences and have interacted with personnel at ARL, NVESD, ECBC, ARDEC and other labs with the goal of developing collaborations and leveraged funding. Dr. Healey also led a session on applications at the Workshop on Distributed Video Sensor Networks at UC Riverside and delivered a plenary talk at the annual SPIE Photonics Conference in San Diego.

7 Scientific Accomplishments

We have developed innovative spectral/spatial/temporal models for HSI data that support current needs as well as enable future research. Methods for ensuring invariance to environmental variability in 3D scenes allow the models to be used over a broad range of conditions and dimensionality reduction techniques have been used to allow the models to be applied efficiently. The new models have been used to develop automated estimation and classification tools that address several application areas including the characterization of ballistic impacts, target detection, clutter characterization, and face recognition. We have demonstrated the performance of these tools over a range of data. We expect that the generality of our approach will enable the new methods to advance the state-of-the-art for several application areas and to support missions involving a wide range of HSI sensors and imaging configurations. This project has also trained graduate students in areas of interest to the DoD.

8 Conclusions

We have developed three-dimensional Gabor filters as a tool for modeling spectral/spatial information in multiband images. These filters provide an efficient mechanism for sampling a frequency domain representation for multiband image data. We have also developed methods for selecting the Gabor filters that provide the most discriminatory power for a given application. The new approach has been applied to several application areas that include the characterization of ballistic impacts, target detection, face recognition, and clutter characterization.